SHORT COMMUNICATION: STAPP CAR CRASH CONFERENCE

Bridging HBM Connect® and ATD Chest Metrics Using Functional Mapping for Crash Application

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ABSTRACT – Human Body Models (HBMs) are gaining recognition by consumer agencies as tools to enhance vehicle safety by complementing traditional Anthropomorphic Test Devices (ATDs). However, integrating HBMs into product development poses challenges in aligning their injury metrics with those of ATDs. This study aims to develop chest deflection mapping functions between the HBM Connect® 50M and two widely used ATD finite element (FE) models: THOR-50M and H3-50M. Frontal chest loading scenarios from the qualification catalogue (Euro NCAP CP 550) were simulated in LS-DYNA (Synopsys) to replicate crash conditions. Matched-pair simulations enabled comparison of chest deflections, with HBM outputs defined to replicate the IR-TRACCs of THOR-50M and sternum potentiometer of H3-50M. Peak chest deflections were used to create mapping functions, ensuring R^2 values above 0.9. A follow-up comparison with the mapping functions using the Gold-Standard GS2 sled test showed strong correlation with THOR-50M and moderate correlation with H3-50M simulated chest deflections values. Future work will incorporate additional sled cases to further refine and validate these mapping functions for frontal impact applications.

INTRODUCTION

Virtual Testing (VT) is increasingly recognized by consumer protection agencies as essential for vehicle safety [Klug et al. 2023], complementing physical crash tests with digital ATDs and Human Body Models (HBMs) to better reflect real-world crash scenarios. HBMs face adoption challenges particularly due to safety engineers' limited experience with them. Unlike ATDs, which have well-established workflows and benchmarks, HBMs lack standardized practices, making their integration into product development workflows difficult. To bridge this gap, it is crucial to define methodologies and establish meaningful correlation between HBM outputs and familiar ATD-based metrics, enabling engineers to apply their existing knowledge. Peak chest deflection, a key thoracic injury risk indicator, exemplifies this need. Any rib strain-based injury risk in HBMs is challenging for product development to interpret given the absence of standardized threshold values for element strains. This study establishes mapping functions between HBM Connect® 50M and two ATDs (H3-50M and THOR-50M) to translate HBM chest deflection data into metrics familiar to product development engineers.

HBM Connect® 50M has been previously validated for the chest region for several hub impact [Kroell et al. 1971, Yoganandan et al. 1997], belt loading [Kent et al. 2004, Salzer et al. 2009], and the sled level [Shaw et al. 2009] frontal load-cases.

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METHODS

Previous studies used hub impact [Kroell et al. 1971] and tabletop loading [Kent et al. 2004] to study thoracic injuries in cadavers. The current study mimicked these cadaver tests with virtual models. A total of eighty-four thoracic load cases were simulated in LS-Dyna (Synopsys) with three virtual models from Humanetics Group (Table-1).

Table 1. Load case matrix

Virtual models	Loading conditions
1) H3-50M (*v1.7.1*) 2) THOR-50M (*v1.9.2*) 3) HBM Connect® 50M (*v2.0*)	Hub Impact [Kroell et al. 1971]
	Tabletop Single Diagonal Belt [Kent et al. 2004]
	Tabletop Double Diagonal Belt [Kent et al. 2004]
	Tabletop Distributed Belt [Kent et al. 2004]

Hub Impact

All three virtual models (Table 1) were oriented to have a posture consistent with test setup. A 152 mm diameter, 23.4 kg cylindrical hub was positioned at the 4th intercostal space of HBM Connect® 50M, aligned parallel to the sternum. The same impact location was replicated for the H3-50M and THOR-50M (Figure 1). Impact speeds ranging from 1 to 7 m/s (in increment of 1 m/s), were simulated to produce chest deflections between 5 mm and 80 mm in ATD virtual models, covering the range for NHTSA [Eppinger et al. 1999] and Euro NCAP deflection thresholds.

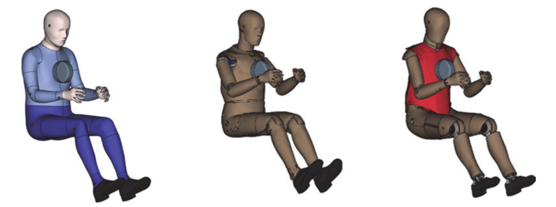

Figure 1: Hub loading for the HBM Connect® 50M, H3-50M and THOR-50M, as shown from left to right for Kroell et al. 1971.

Tabletop Seatbelt Variations

All the three virtual models were positioned in supine posture on a tabletop setup. Belt paths were aligned to ensure consistency across all three virtual models. The belt was attached to a rigid frame and anterior thorax was loaded in a controlled manner. Loading speeds matched those used in hub tests (1 to 7 m/s in increment of 1 m/s). Three belt configurations (Figure 2 and Table 1) were assessed to target different thorax regions.

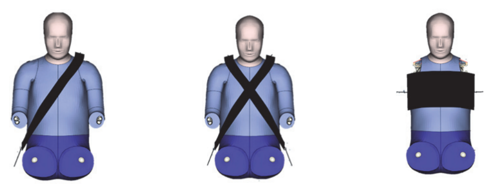

Figure 2: HBM Connect® 50M in Single diagonal belt (left), double diagonal belt (middle) and distributed belt (right) for Kent et al. 2004.

Mapping Function Verification

The study verified the simulation predicted chest deflections outputs against the mapping functions outputs using sled simulations. All three virtual models were set up in a frontal impact sled configuration (Figure 3) replicating the Gold Standard 2 sled [Shaw et al. 2009], with consistent thorax orientation and seatbelt routing aligned with deflection output locations as in PMHS tests.

Figure 3: Gold Standard 2 sled loading for HBM Connect® 50M, H3-50M and THOR-50M, as shown from left to right for Shaw et al. 2009.

Data Analysis

To be analogous with the H3-50M sternum potentiometer, a nodal output at the 4th intercostal space on sternum bone of HBM Connect® 50M was used with the outputs following the local coordinate system attached to the spine at the 9th thoracic vertebrae as shown in Figure 4 (left).

For the THOR-50M IR-TRACCs, nodes at locations near the costal cartilage and spine of HBM Connect® 50M analogous to IR-TRACC mount locations were defined to output the deflections as shown in Figure 4 (right). Maximum of all the four IR-TRACCs (R_{max}) analogous deflection from HBM Connect® 50M were matched with corresponding ATD measurements.

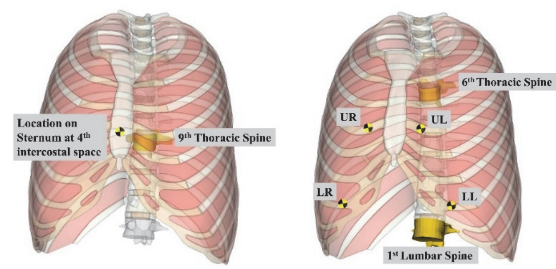

Figure 4: H3-50M (left) and THOR-50M (right) analogous output for chest deflections for the HBM Connect® 50M.

RESULTS

All eighty-four simulations resulted in normal termination. Peak chest deflections from hub and tabletop seatbelt loading across all speeds for H3-50M and HBM Connect® 50M are mapped (Figure 5). The H3-50M deflections ranged from 5 mm to 65 mm. A linear regression (R^2 = 0.9325) was established to predict the HBM Connect® 50M deflections.

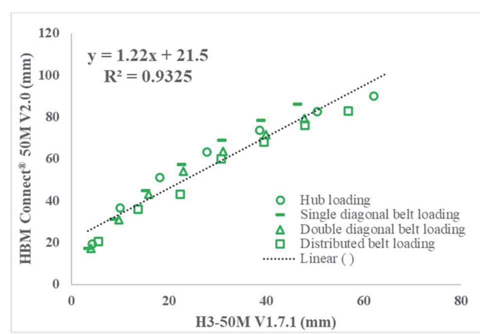

Figure 5: Mapping of peak chest deflection for H3-50M and HBM Connect® 50M.

Similarly, Figure 6 shows peak deflections (R_{max}) for THOR-50M (ranging from 10 mm to 80 mm) and HBM Connect® 50M mapped with a linear regression model (R^2 = 0.9469).

A cross plot for the THOR-50M versus H3-50M for the peak chest deflection as shown in Figure 7 reveals that the H3-50M is stiffer producing less chest deflections.

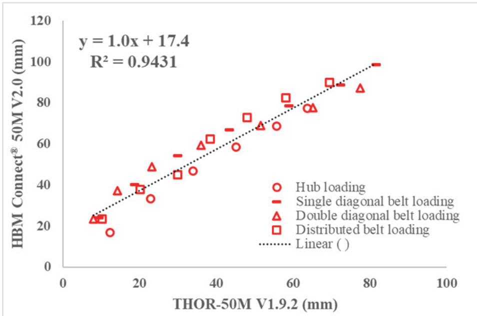

Figure 6: Comparison of peak chest deflection of THOR-50M Euro NCAP vs HBM Connect® 50M.

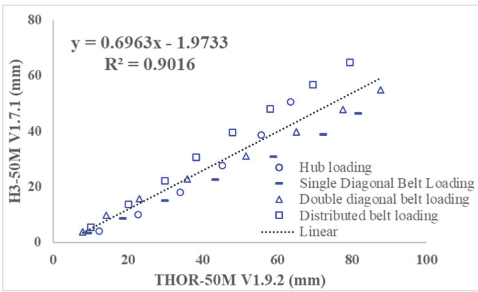

Figure 7: Comparison of peak chest deflection of THOR-50M Euro NCAP vs H3-50M.

DISCUSSION

This study does not propose injury thresholds for HBM but aims to bridge the gap in interpreting HBM Connect® 50M chest deflection using ATD-like outputs. A quantifiable relationship was established between HBM Connect® 50M and two frontal ATDs, mimicking corresponding instrumentation. While future research may refine HBM deflection metrics, this work focuses on defining chest deflection through comparable ATD methods.

The developed linear regression mapping functions demonstrated strong predictive accuracy, with R^2 values above 0.9. Simulation data from the Gold Standard 2 sled showed a peak deflection of 16 mm for the H3-50M, corresponding to 45.6 mm in HBM Connect® 50M, while the mapping predicted 41 mm (4.6 mm difference) reflecting a moderate correlation. For THOR-50M, a 28 mm deflection in GS2 sled corresponds to 45 mm in HBM Connect® 50M, with a predicted value of 45.4 mm from the mapping function showing excellent accuracy (0.4 mm difference).

To strengthen confidence in the H3-50M predictions, additional regression models were evaluated. The quadratic ($R^2 = 0.974$) and power-law ($R^2 = 0.969$) fits exhibited better correlations than the linear model ($R^2 = 0.943$). For the GS2 sled test, the deflection prediction error was lowest for the power-law fit (1.7 mm), followed by the quadratic fit (3 mm) showing improvement in predictions from the linear regression mapping functions for the H3-50M.

The data set used to develop the mapping functions included selected thoracic loading configurations, limiting coverage of real-world crash conditions. To improve predictability, additional scenarios such as loading with airbags, and oblique impacts will be explored. Further validation through full vehicle crashes and sled tests will broaden the mapping function applicability.

CONCLUSION

This study developed linear regression-based mapping functions to correlate chest deflections between HBM Connect® 50M and two frontal ATDs: H3-50M and THOR-50M. In controlled thorax loading scenarios, the two ATDs showed distinct peak chest deflection patterns compared to the HBM Connect® 50M. Strong correlation coefficients and sled validation results confirm that the proposed mapping functions provide reliable predictive accuracies. These functions enable safety engineers to apply HBM-derived data more effectively in real-world product development.

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